REMARKS/ARGUMENTS

In the Office Action dated Dec. 22, 2008, claims 1 - 5, 7 - 11, 15 - 19, 21 and 22 were rejected under 35 U.S.C. Section 103(a) as unpatentable over Qin, U.S. Patent Publication 2005/0283072 in view of Lin, U.S. Patent 6,068,597. Reconsideration of the claims in view of the amendments and the following remarks is respectfully requested.

Amendments

Independent claims 1, 10, and 15, have been amended to recite an ultrasound wave that is modulated at one or more frequency to induce a vibration in a viscous medium. The vibration can then be used to quantify a property of elasticity based on the resonant spectrum.

As set forth in the attached pages from Ultrasonic Exposimetry, Ziskin and Lewin, CRC Press, 1993, when an ultrasound wave propagates within a medium, the ultrasound wave produces two forces within the medium: a dominant vibrational force (first order effect) which acts on the medium at the frequency of the ultrasound wave, in the megahertz range, and a secondary, and significantly smaller, static force (second order effect).

As recited in the claims, as amended, the ultrasound wave is modulated (see paragraphs 0024 and 0026 of the application as filed). The modulation causes the static secondary force to oscillate at a selected frequency, producing a small, local, vibrational force oscillating at the frequency of modulation, and located generally at or within several cubic millimeters of the focal point of the transducer. The frequency of oscillation is varied to produce a resonance spectrum, and, because the vibration is confined to a small area within the medium, the resonance characteristic is determined by the local material properties of the medium. It is, therefore, possible to quantitatively solve for material properties (e.g., in units of Pascal for shear modulus)

using, for example, the formulas found in paragraph 0020 of the application as filed. The vibration generated by the secondary force can be measured and used to directly solve for properties of the medium.

The Prior Art References

As discussed above, all of the pending claims are presently rejected based on the combination of Qin and Lin.

Qin discloses a method for calculating bone mineral density and material strength/stiffness. An ultrasound wave is directed through a bone specimen from a first transducer 12 to a second transducer 14. (See Fig. 1a; paragraph 46; paragraph 56) A computer 22 calculates propagation times of signals transmitted through the bone, calculates propagation velocity through the bone, and other parameters. (Paragraph 64) These parameters are used in mathematical equations, and particularly in a regression analysis (paragraphs 68 - 80) which relates measured values of the propagation velocity to stiffness, and particularly to bulk modulus, which is a measure of a substance's resistance to compression.

Lin discloses a system which uses ultrasonic Doppler spectrometry to produce a vibrational resonance spectra of tissues. In this system, a variable frequency tone generator 124 produces a waveform, which is provided to a pair of audio transducers 112. The audio transducers induce vibrations into a medium or tissue to be scanned (Col. 4, lines 52 - 60), at frequencies distributed between 10 and 350 Hz (Col. 4, lines 66 - 67). This vibrational force is generated by the first order, linear effect of the acoustic transducers. As discussed above, a first order force is a relatively large force, and therefore extends globally through the medium, vibrating the entire object.

After a vibration is induced, an ultrasound transducer produces ultrasonic waves which are directed within the medium, and Doppler signal processing is used to detect frequency shifts in the returning echoes. A spectrometer examines the Doppler amplitude variation as a function of the stimulus frequency, and provides a vibrational resonance spectral "signature" curve for the material or tissue being imaged. (Col. 5 lines 47 - 49) Because the applied force is "global", the resonance spectrum is affected by both the material properties and the geometry (shape and size) of the material. As seen by reference to Figs. 6 and 9, because of the complications of the geometry of the material, the resultant resonance spectrum is a "multi-peak" resonance spectrum (Col. 7, lines 5 - 11). The influence of the geometry of the object cannot be separated from the material properties. Therefore, although this method can provide a qualitative mapping of tissue, e.g. detect and differentiating tumors (Abstract), this method does not and cannot be used to provide a quantitative measurement of shear modulus.

Independent Claim 1

Independent claim 1, as amended, recites directing an ultrasound wave in a viscous medium, and modulating the ultrasound wave at a frequency of vibration to produce a vibrational force on the medium at a focal point of the transducer. A vibrational velocity of the medium is monitored in the focal region and the vibrational velocity is correlated with the frequency of vibration. These steps are repeated for a plurality of frequencies to develop a resonance spectrum of the medium. An elasticity property is determined from the resonance spectrum.

The cited Qin and Lin references do not disclose all of the elements of claim 1, either alone or in combination. Neither cited reference discloses the use of a modulated ultrasound wave to produce a vibrational force on the medium.

Lin discloses the use of ultrasound only to detect vibrations. The ultrasound is not modulated, and does not induce vibrations for resonance characterizartion. Acoustic transducers, rather, are used to induce the vibration in the medium. As discussed above, when acoustic transducers are used to induce a vibration, the vibration is large and extends throughout the object, resulting in a resonance spectrum that includes multiple peaks. This spectrum is substantially different from the spectrum induced in the invention as recited in claim 1.

Qin discloses directing an ultrasound wave through a bone, and calculating time and velocity parameters of the propagation of the wave through the bone. Qin fails to disclose producing any vibrational force, and, in fact fails to discuss any vibration.

Neither of the cited references, moreover, discloses determining an elasticity property of the tissue from the resonance spectrum. Qin, as discussed above, does not induce a vibration, and does not produce a resonance spectrum at all. Lin produces a multi-peak resonance spectrum based on Doppler shift data, and uses this spectrum to reconstruct an image. Lin does not correlate a resonance spectrum with an elasticity parameter. Therefore, the cited references do not disclose all of the elements of claim 1, either alone or in combination, and the Applicants respectfully request that the rejection of claim 1 and associated dependent claims be withdrawn.

Claims Depending from Claim 1.

Dependent claims 2 - 9 and 22 include all of the limitations of claim 1 and are therefore patentable over the cited references for the reasons set forth above. In addition, these claims recite additional limitations which are not found in the prior art as set forth below.

Claim 2 further recites that the step of modulating the ultrasound wave comprises modulating an amplitude of the ultrasound wave. Neither of the prior art references disclose

modulating an amplitude of an ultrasound wave, and claim 2 is believed patentable over the cited reference for this reason as well.

Claim 5 further recites the step of comparing a resonance spectrum to a stored resonance spectrum to determine the elasticity property. Again, the prior art references neither teach nor suggest such a step.

Claim 8 recites that the elasticity property comprises at least one of a shear modulus and a shear viscosity. Neither of the cited references discloses a method for quantifying a shear modulus or a shear viscosity, or in fact any method that would be capable of providing such a quantification.

Claim 22 recites the step of varying the frequency at which the ultrasound wave is modulated in a range between zero and eight kilohertz. Again, the cited references do not modulate an ultrasound wave, and therefore cannot modulate the wave within this range of frequencies.

In view of the distinctions cited, therefore, claims 1 - 9 and 22 are not obvious in view of the cited references, and the Applicants respectfully request that the rejection of these claims be withdrawn.

Independent Claim 10

Independent claim 10, as amended, recites directing an ultrasound wave modulated at a first oscillating frequency at a focal point in the tissue, measuring a vibrational velocity of the tissue at the focal point, and varying the oscillating frequency over a range selected to produce a resonant frequency response in the tissue. The resonant spectrum is then correlated to a known elasticity parameter.

Again, neither of the cited references discloses the use of an ultrasound wave that is modulated to induce a vibration in tissue. Qin, as discussed above, does not disclose a frequency vibration for resonance characterization at all. Lin uses an acoustic transducer to induce a vibration.

Neither of the cited references discloses inducing the vibration at a specific focal point, or discloses a method which renders this possible. Qin, again, fails to induce a vibration at all. Lin employs multiple audio transducers which are directed at a medium to be studied. These transducers are directed at the medium in general, and induce a global vibration which is affected by both the size and shape of the medium, as well as the material properties. Therefore, elasticity parameters cannot be quantitatively resolved using this method.

Neither of the cited references, furthermore, discloses quantitatively correlating a resonant spectrum with a known elasticity parameter. Qin, as discussed above, does not determine a resonant spectrum at all. Lin produces a characteristic curve which can include a number of resonant frequencies, and uses this data to produce images.

Claim 10, therefore, cannot be obvious in view of the cited references, and the applicants respectfully request that the rejection of claim 10 and associated dependent claims be withdrawn.

Claims Depending from Claim 10

Dependent claims 11 - 14 and 23 include all of the limitations of claim 10 and are therefore patentable over the cited references for the reasons set forth above. In addition, these claims recite additional limitations which are not found in the prior art as set forth below.

Claim 14, as amended, recites the step of varying the oscillating frequency in a range between zero and eight kilohertz. Again, the cited references do not disclose any method of

modulating an ultrasound wave, and cannot disclose modulating the wave within this frequency range.

New claim 23 recites that the known elasticity parameter comprises at least one of a shear modulus and a shear viscosity. Neither of the cited references discloses a method for quantifying a shear modulus or a shear viscosity, or in fact any method that would be capable of providing such a quantification.

In view of the distinctions cited, therefore, claims 10 - 14 and 23 are not obvious in view of the cited references, and the Applicants respectfully request that the rejection of these claims be withdrawn.

Independent Claim 15

Claim 15 is directed to an apparatus for determining an elasticity property of a viscous medium. The apparatus comprises an ultrasound transducer for applying an ultrasound beam modulated at a selectively varying frequency at the viscous medium, and a detector for measuring a velocity and a frequency of vibration of the medium at a focal point of the ultrasound transducer. A processing unit drives the ultrasound transducer at varying vibration frequencies over a selected frequency range, receives the velocity and frequency of vibration from the detector; and determines a resonant spectrum at selected positions within the medium. The processing unit determines a shear elasticity or a shear viscosity from the resonance spectrum.

As discussed above, neither of the cited references discloses the use of an ultrasound wave that is modulated to induce a vibration in tissue. Neither of the cited references discloses determining an elasticity parameter based on the resonant spectrum. Moreover, neither of the

cited references discloses any method for determining a shear elasticity or a shear viscosity. At best, Qin discloses a method for determining the bulk modulus, a parameter that is based on compressive rather than the shear modulus of tissue, and that is at least an order of magnitude larger than a shear modulus parameter. As the cited references fail to disclose all of the elements of the claim, claim 15 cannot be obvious in view of the cited references, and the applicants respectfully request that the rejection of claim 15 and associated dependent claims be withdrawn.

Claims Depending from Claim 15

Dependent claims 16 - 19 and 24 include all of the limitations of claim 15 and are therefore patentable over the cited references for the reasons set forth above. In addition, these claims recite additional limitations which are not found in the prior art as set forth below.

Claim 18 recites that the transducer produces an amplitude modulated signal. New claim 24 further recites that the ultrasound wave is modulated in a selected frequency range is in a range between zero and eight kilohertz. Again, the prior art references fail to disclose any method for modulating an ultrasound wave, do not disclose amplitude modulation of an ultrasound wave, or modulation in the frequency range recited in claim 24.

In view of the distinctions cited, therefore, claims 15 - 20 and 24 are not obvious in view of the cited references, and the Applicants respectfully request that the rejection of these claims be withdrawn.

Conclusion

In view of the foregoing amendments and remarks, the Applicants submit that claims 1 - 22 are in condition for allowance, and respectfully request that a notice of allowance fore these claims be issued.

The Commissioner is authorized to charge any fees under 37 CFR § 1.17 that may be due on this application to Deposit Account 17-0055. The Commissioner is also authorized to treat this amendment and any future reply in this matter requiring a petition for an extension of time as incorporating a petition for extension of time for the appropriate length of time as provided by 37 CFR § 136(a)(3).

Respectfully submitted,

Dated March 23, 2009

By: /Terri S. Flynn/

Terri S. Flynn
Quarles & Brady LLP
Reg. No. 41,756
Attorney for Applicant
411 East Wisconsin Avenue
Milwaukee, WI 53202-4497
(414) 277-5229

ULTRASONIC EXPOSIMETRY

Edited by

MARVIN C. ZISKIN, M.D.
Department of Diagnostic Imaging
Director, Center for Biomedical Physics
Temple University Medical School
Philadelphia, Pennsylvania

PETER A. LEWIN, Ph.D.
Department of Electrical and Computer Engineering
and Biomedical Engineering and Science Institute
Drexel University
Philadelphia, Pennsylvania

CRC Press
Boca Raton Ann Arbor London Tokyo

Library of Congress Cataloging-in-Publication Data

Ultrasonic exposimetry / edited by Marvin C. Ziskin and Peter A. Lewin.
p. cm.
Includes bibliographical references and index.
ISBN 0-8493-6436-1
1. Diagnosis, Ultrasonic. 2. Radiation dosimetry. I. Ziskin, Marvin C. II. Lewin, Peter A.
[DNLM: 1. Ultrasonics. 2. Ultrasonography. WB 289 U447]
RC78.7.U4U42 1992
616.07'543--dc20
DNLM/DLC
for Library of Congress 92-21017
CIP

Direct all inquiries to CRC Press, Inc., 2000 Corporate Blvd., N.W., Boca Raton, Florida, 33431.

International Standard Book Number 0-8493-6436-1

Library of Congress Card Number 92-21017

Printed in the United States of America 1 2 3 4 5 6 7 8 9 0

Printed on acid-free paper

luminescence; and the hot-spot theory, which depends directly on high temperatures produced during cavity collapse. In any event, sonoluminescence can be enhanced by the addition of luminol (5-amino-2,3-dihydro-1,4-phthalazinedione) to the aqueous medium.[100] The phenomenon is unlikely to occur with stable cavitation, except in standing waves.[101] Sonoluminescence certainly can be used to detect acoustic cavitation generated by microsecond pulses of ultrasound at 1 MHz.[102] Although it can sometimes be seen with the naked eye, it is usually better to photograph it through an image intensifier.[103]

D. RADIATION FORCE

"It might be said that radiation pressure is a phenomenon that the observer thinks he understands — for short intervals, and only now and then." Thus wrote R. T. Beyer[104] as recently as 1978. What is clear is that an ultrasonic wave exerts a static force on any interface or in any medium across which there is a decrease in ultrasonic power being transported in the direction of wave propagation.

In the case of complete absorption of a finite beam of plane waves,

$$F = W/c \tag{69}$$

where F is the force due to "radiation pressure" and W is the ultrasonic beam power. The force F acts in the vector direction of the propagation of the wave. At normal incidence, the force on a perfect reflector (SWR $= \infty$) is equal to twice the force that would act on a perfect absorber in the same situation. At oblique incidence, the direction of the resultant force may be calculated by resolving the forces due to the incident and reflected beams.

It is dimensionally correct to consider radiation force in terms of momentum change. The transport of energy by a wave is equivalent to a flow of momentum across the plane normal to the ultrasonic beam. Thus, at a perfect absorber there is a single change in momentum, but at a perfect reflector there are two momentum changes because the wave is unattenuated. For plane waves, the forces corresponding to oblique incidence and partial reflection can be calculated from the corresponding momentum vectors.

Insight into the controversial theories of the physics of radiation force requires an initial review of the literature.[105] Pragmatically, what is clear to the experimental physicist is that radiation force measurements are robustly applicable and the esoteric debates over linearity and nonlinearity, dimensionality, bounding, and so on can happily be forgotten. That having been said, it is safe to begin to consider the radiation force exerted by an ultrasonic beam on a sphere, since this obviously leads to an attractive method for measuring the intensity at any point in a fluid. Thus, the deflection Δ of a suspended sphere is given by[106]

$$\Delta = \frac{\pi a^2 l Y}{Mgc} I \tag{70}$$

where a is the radius of the sphere, l is the length of the supporting filament, M is the effective weight of the sphere in the medium in which c is the propagation speed, g is the acceleration due to gravity, and I is the local ultrasonic intensity; Y is a numerical function the value of which depends on the material and dimensions of the sphere, and the characteristic impedance of the supporting medium. Suitably chosen spheres have Y values of about 1.0, since other values of Y change rapidly with size of sphere and frequency of ultrasound; for example, for a stainless steel ball with ka = 3 to 5, $Y \simeq 0.8$.

When ultrasound travels through a liquid, a fraction of the energy carried by the wave is absorbed. The resultant radiation force causes the liquid to stream. (The phenomenon is quite distinct from the acoustic microstreaming associated with bubble activity.) In the case of a diverging wave in a tube, the streaming velocity v is given by[107]

$$v = \frac{2\alpha\, d^2}{\gamma \rho c} I \tag{71}$$

where I is the ultrasonic intensity, d is the diameter of the beam, γ is the kinematic viscosity of the liquid of density ρ, and c is the propagation speed in the liquid; α is the absorption coefficient of the liquid at the fundamental ultrasonic frequency. In fact, the harmonic content of the ultrasound (or the ultrasonic pulse) has a major effect on the streaming velocity[108] and it has to be remembered that streaming requires a finite time (typically 0.5 s) to become estabished.

When a beam of ultrasound of sufficient intensity is passed through a liquid and directed at an air interface, "atomization" of the liquid may occur. Liquid particles are ejected from the surface in a fountain and, under suitable conditions, a very dense fog may be produced. At low rates of fog production (less than about 0.01 ml s^{-1} of liquid atomization per square centimeter of surface area), it has been shown[109] that the median particle diameter d_m is given by

$$d_m = 0.34(8\pi\sigma/\rho f^2)^{1/3} \tag{72}$$

where σ is the surface tension and the other symbols have their usual meanings.

IV. RECEPTION OF ULTRASOUND

A. PIEZOELECTRIC DEVICES

Piezoelectric transducers can act both as generators and as receivers of ultrasound. The piezoelectric coefficient g is defined as the electric field produced under open-circuit conditions per unit applied stress. The g coefficient describes the performance of a piezoelectric transducer when operating